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MINISTRY OF SUPPLY

**MARINE AIRCRAFT
EXPERIMENTAL ESTABLISHMENT
FELIXSTOWE**

INVESTIGATION OF HIGH LENGTH/BEAM RATIO SEAPLANE
HULLS WITH HIGH BEAM LOADINGS

HYDRODYNAMIC STABILITY PART 8

THE STABILITY AND SERAY CHARACTERISTICS OF MODEL E

by

D.M. RIDLAND, G.I.Mech.E., A.R.Ae.S.

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Report No. F/Res/242

December 1953

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT, FELIXSTOWE, SUFFOLK.

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S U M M A R Y

In this report results are presented of tests on the hydrodynamic characteristics of model E of the series. This model has a length/beam ratio of 13 (the forebody being 6 beams in length and the afterbody 7 beams), zero forebody warp, an afterbody to forebody keel angle of 6° , and a straight transverse step with a step depth of 0.15 beams.

The tests comprised the determination of longitudinal stability limits without slipstream at $C_{\Delta_0} = 2.25$ and 2.75 , an investigation of spray at these loadings, and an assessment of directional stability. A short discussion of the results is also included.

Addendum to M.A.E.E. Report No. F/Res/242

Figure 10 should be disregarded, as subsequent measurements have shown the formula used to be somewhat inaccurate.

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1. INTRODUCTION

In this report results are given of tests on the stability and spray characteristics of Model E of the series detailed in Reference 1, a list of which is reproduced in Table I. Full details are given in this reference of the considerations affecting the design of the models, but it may be mentioned here that Model E has a length/beam ratio of 13 (the forebody being 6 beams in length and the afterbody 7 beams), zero forebody warp, an afterbody to forebody keel angle of 6° , and a straight transverse step with a step depth of 0.15 beams. Figure 1 gives the hull lines of the model and Figure 2 photographs of it. Full hydrodynamic and aerodynamic data relevant to this model are given in Tables II and III. The techniques used in the tests and the presentation of results, together with the reasons for using them, are considered in References 1 and 2, though a brief summary is given in the next section.

The tests performed included the determination of longitudinal stability limits at $C_{\Delta_0} = 2.25$ and 2.75 without slipstream, of the spray characteristics at these values of C_{Δ_0} , and an assessment of directional stability for $C_{\Delta_0} = 2.75$, with the model constrained in roll.

Figures are included showing the limits and there are a number of subsidiary diagrams. Where possible results have been presented non-dimensionally.

Comparisons of the results obtained with those for other models (References 3 to 7) will be made in further reports; consideration is restricted in this report to factors peculiar to Model E.

2. DESCRIPTION OF TESTS

2.1. General

All tests were made with one C.G. position, no slipstream, zero flap and at steady speeds only. The pitching moment of inertia of the model was 25.02 lb. ft.^2 in all longitudinal stability tests.

2.2. Lift

A limited number of runs were performed at constant speed with the model clear of the water to check that there was no significant variation in lift from the values obtained for previous models, with which identical wings were used, these runs being carried out at several elevator settings and keel attitudes. The resulting curves are given in Figure 3.

2.3. Longitudinal Stability

Longitudinal stability tests were made by towing the model from the wing tips on the lateral axis through the centre of gravity, the model being free in pitch and heave. The value of the elevator setting was selected before each run, and the model towed at constant speed. The angle of trim was noted in the steady condition, and if the model proved stable at the speed selected it was given nose-down disturbances to determine whether instability could be induced, the amount of disturbance necessary to cause instability being in the range $0 - 8^\circ$. The larger amounts of disturbance were required near the undisturbed lower limit at high speeds. Stability limits were built up by these methods, the disturbed limits representing the worst possible case. Tests were carried out with $C_{\Delta_0} = 2.25$ and 2.75 , and the corresponding trim curves and stability limits are given in Figures 4 - 7. The limits for the different values of C_{Δ_0} are plotted together in Figures 8 and 9 for comparison on a C_T base and the undisturbed lower limits, transposed to a draught base by the formula of Reference 1 for the equivalent wedge, are plotted in Figure 10; Figures 11 and 12 are subsidiary curves necessary for this transposition.

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When steady porpoising occurred, either with or without disturbance, the amplitude was noted, amplitude for this purpose being defined as the difference between the maximum and minimum trims attained in the oscillation. These amplitudes are plotted in Figures 13 and 14, for the various cases concerned.

2.4. Spray and Wake Formation

Photographs were taken of the spray, from three different positions, over a range of speeds and with elevators set at -8° . A number of these photographs are reproduced in Figures 17 - 20. They have been used to determine the projections of the spray envelopes on the plane of symmetry of the model at the different values of C_{Δ_0} , and these projections are plotted in Figure 21. It should be noted that in plotting the projections velocity spray has in general been ignored.

In addition to the spray photographs, photographs of the wake region were taken from two different positions and are reproduced in Figures 15 and 16. These photographs covered a range of speeds and elevator settings, the combinations being selected to give the maximum possible variation of wake formation and position relative to the afterbody in the stable planing region.

2.5. Directional Stability

In the directional stability tests the model was pivoted universally at the C.G. and then separately constrained in roll, so that it was effectively free in pitch, yaw and heave. The model was towed from the C.G. and moments to yaw the model were applied by means of strings attached to the wing tips and in the same horizontal plane as the C.G.

Steady speed runs were made with the elevators set at 0° , the model being yawed up to at most 18 degrees and the values of yaw giving equilibrium determined by the operator by assessment of the direction of the resulting hydrodynamic moment on the model. The occurrence of very high drag forces at large angles of yaw at high speeds made it impossible to investigate some regions. The value of C_{Δ_0} in these tests was 2.75 and the resulting stability diagram is plotted in Figure 22.

2.6. Elevator Effectiveness

Curves of elevator effectiveness calculated from the longitudinal stability diagrams are given in Figures 23 and 24.

3. DISCUSSION OF RESULTS

The lift curves (Figure 3) do not vary substantially from those of the basic model, with which identical wing and tail units were used.

Longitudinal stability without disturbance is good, for this model, at both values of C_{Δ_0} used (Figures 4 and 6). There is, in each case, a wide stable band extending from zero to take-off speeds, and the unstable region above the upper limit is very small. The effect of increasing the load coefficient from 2.25 to 2.75 is to raise the lower limit by $3/4^\circ$ at the high speed end and by about 2° at the hump end (Figure 8). The upper limit is moved up the speed scale, maintaining the same mean attitude, and, at the higher weight, upper limit instability is almost eliminated.

Longitudinal stability with disturbance at $C_{\Delta_0} = 2.25$ is good (Figure 5). The only change which has been wrought by disturbance is the raising of the lower limit by only 2° at the high speed end, and this effect decreases progressively with speed down to $C_v = 7$, when undisturbed and

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disturbed limits coincide. At the higher weight ($C_{\Delta_0} = 2.75$) however, disturbance produces a marked change in the limits (Figure 7). The high speed lower limit is raised $2\frac{1}{2}^\circ$, an unstable band appears across the diagram and the upper limit unstable region, although still remaining small, is increased.

Hump speed, which is rather high, remains unaltered by weight increase, and, apart from a small general increase in attitude (from 9.1° to 9.7° at the hump) and a kink occurring at high speeds and attitudes, the trim curves are similar. This kink, which can be seen in the trim curve $\eta = -8^\circ$ at $C_{\Delta_0} = 2.75$ (Figure 6) and to a lesser extent in $\eta = -12^\circ$, is possibly due to suction on the afterbody causing an increase in attitude, which is then decreased by the planing of the afterbody, by spray from the main step hitting the afterbody or by the dying away of the suction as model draught decreases. In all regions an increase in load causes an increase in the amplitude of porpoising, (Figures 13 and 14) and at an initially unstable point the amplitude of porpoising is increased by disturbance.

The two undisturbed lower limits have been transferred to a draught base ¹ in Figure 10. The effect of load is to decrease draught for a given attitude at higher draughts, and this effect decreases with decreasing draught until the two limits coincide at $d/b = 0.14$. It should be noted however, that these effects are very small being of the order of 0.07 in. in the worst case.

The load coefficient curves (Figures 11 and 12) are used as an intermediate step in the draught base transposition and will give take-off speeds if they are extended to $C_{\Delta_0} = 0$. As would be expected the effect of increased weight is to move the whole diagram up the load coefficient scale while leaving it almost unchanged in form.

Photographs of the wake with the model undisturbed and stable at representative speeds and attitudes are given in Figures 15 and 16 respectively. The position of the aft step relative to the wake is shown in each case and with these flow conditions various known reactions to disturbance (from the corresponding points α_k , C_v on the stability diagrams) can be associated. Considering Figure 15, the lower weight case ($C_{\Delta_0} = 2.25$), it will be remembered that disturbance produced little change in the limits for this weight. Views (a) and (d) are medium and low attitude, low speed cases respectively. In the medium attitude case (a), the afterbody can be seen to be planing for about 1 beam forward of the step (the chequer board pattern consists of $\frac{b}{4}$ squares). From Figures 4 and 5, (a) is well into the stable region and is completely unaffected by disturbance. Similar remarks apply to case (d); about $\frac{1}{4}$ beam of the afterbody forward of the step is planing and, although this point is just above the limit, disturbance has no effect on the stability. Photographs (b) and (c) are of high and low attitude, moderately high speed cases. In (b) the afterbody is just planing and one might expect to be approaching the two-step porpoising state; in fact (b) lies 1° below the upper limit and stability at this point is unchanged by disturbance. In the low attitude view (c) the aft step is well clear of the wake and instability does result from disturbance. The last case (e) is in the mid-planing region and, although the afterbody is clear of the wake, it is not well clear. This point lies well within the stable band both with and without disturbance. From the cases considered only the high speed, low attitude one (c), is rendered unstable by disturbance and this is the occasion on which the afterbody - wake clearance is the greatest.

Similar remarks apply to the higher weight case, Figure 16, where the onset of instability by disturbance occurs in (c), (d) and (e). The actual shape of the wake can be judged from the photographs generally; it is narrow, of almost constant cross section at lower attitudes and fairly deep. The trough can be seen to be filling in on some of the rearmost views.

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/Spray

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Spray photographs for individual speeds, mainly in the displacement range, are shown in Figures 17 - 20. The spray characteristics of this model are poor and this is most evident at $C_V = 3$ to 4 for both weights. At $C_V = 3$ in particular the spray strikes the wing leading edge in the lower weight case, and goes right over the wing in the higher. These poor characteristics accrue from the long afterbody, which keeps the attitude low and this in turn causes the spray origin to be near the bow. It may be emphasised that the forebody of this model is identical to that of Model A, i.e. it has no refinements of any kind. The blank in Figure 20 is due to the camera line of sight being interrupted by spray sufficiently to spoil the picture. In Figure 21 spray envelopes for both weights have been drawn. The method of obtaining these envelopes differs from that of Reference 1 in that only the longitudinal spray disposition has been considered. The profiles used were taken straight from the side view photographs and a limited parallax error was accepted. Where this error tended to become large the curves have not been drawn. It is suggested that the lateral positions of spray peaks can be judged qualitatively from the three quarter views if this becomes necessary. The aim of Figure 21 is to form a convenient comparison basis and the effect of increased weight on spray in this case can readily be seen to be considerable. As the projections are discontinuous because of wing interference the S.M.C. has been indicated to complete the picture.

On directional stability the effects of weight⁵, roll constraint³ and elevator³ are small enough to be neglected and, as breaker strips cause only the deletion of the high speed part of the normal directional diagram¹, Figure 22 shows completely (for practical purposes) the directional stability of Model E.

The diagram indicates pre-hump instability up to $C_V = 4$. At $C_V = 4.3$ the attachment of the lower part of the wake to the afterbody near the rear step causes a line of unstable equilibrium, between which and the speed axis, there is a region of neutral stability. Apart from a point of stable equilibrium at $C_V = 7.6$, this neutral region extends to take-off speeds. The line of unstable equilibrium just mentioned is terminated by full attachment of the wake to the hull side, with the inception of a new line of unstable equilibrium at $\psi = 9.5^\circ$. This full attachment of the wake to the hull side does not produce a violent reaction as might be expected at the higher speeds under consideration, but is followed by only a moderate tendency to increase yaw.

Elevator effectiveness (Figures 23 and 24) shows a marked decrease with increased load $C_V = 7$ and 8, but at $C_V = 9$ this effect almost disappears giving virtually the same effectiveness for $C_{\Delta_0} = 2.25$ and 2.75.

4. CONCLUSIONS

The calm water longitudinal stability characteristics of this model are good in both weight cases, even though the weight effect is significant. The rough water stability at the lower weight is very good, but this performance deteriorates seriously with increased loading. In spite of this deterioration however, it still remains passable.

The spray characteristics, which are directly affected by the long afterbody, are poor and would give trouble with propellers or jet intakes, but they could be modified by changes in forebody design.

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LIST OF SYMBOLS

b	beam of model
d	draught
C_L	lift coefficient = $L / \frac{1}{2} \rho S V^2$ (L = lift, ρ = air density).
C_V	velocity coefficient = V / \sqrt{gb}
C_Δ	load coefficient = Δ / wb^3 (Δ = load on water and w = weight per unit volume of water)
C_{Δ_0}	load coefficient at $V = 0$
C_X	longitudinal spray coefficient = x/b
C_Y	lateral spray coefficient = y/b
C_Z	vertical spray coefficient = z/b {(x,y,z) co-ordinates of points on spray envelope relative to axes through step point }
S	gross wing area
V	velocity
α_K	keel attitude
η	elevator setting
ψ	angle of yaw

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2	J.K. Friswell A.G. Kurn D.M. Ridland	Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings: Hydrodynamic Stability Part 2: The Effect of Changes in the Mass, Moment of Inertia and Radius of Gyration on Longitudinal Stability Limits. M.A.E.E. Report F/Res/233. September 1953.
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7	J.K. Friswell	Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings: Hydrodynamic Stability Part 7: The Stability and Spray Characteristics of Model D. M.A.E.E. Report F/Res/241. November 1953.

/TABLE I

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TABLE I

Models for hydrodynamic stability tests

Model	Forebody warp	Afterbody length	Afterbody-forebody keel angle	Step form	To determine effect of
	degrees per beam	beams	degrees		
A	0	5	6	Unfaired transverse. Step depth 0.15 beam.	Forebody warp
B	4	5	6		
C	8	5	6		
D	0	4	6		Afterbody length
A	0	5	6		
E	0	7	6		
F	0	9	6		
G	0	5	4		Afterbody angle
A	0	5	6		
H	0	5	8		

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TABLE II

MODEL E - HYDRODYNAMIC DATA

Beam at step (b)	0.475'
Length of forebody (6b)	2.850'
Length of afterbody (7b)	3.325'
Angle between forebody and afterbody keels	6°
Forebody deadrise at step	25°
Forebody warp (per beam)	0°
Afterbody deadrise	30°
	(decreasing to 26° at step over forward 40% of afterbody length).
Pitching moment of inertia	25.02 lb.ft. ²

/ TABLE III

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TABLE III

Model Aerodynamic data

Mainplane

Section	Gottingen 436 (mod.)	
Gross area	6.85 sq. ft.	
Span	6.27 ft.	
S.M.C.	1.09 ft.	
Aspect ratio	5.75	
Dihedral	} on 30% spar axis	3° 0'
Sweepback		4° 0'
Wing setting (root chord to hull datum)		6° 9'

Tailplane

Section	R.A.F. 30 (mod.)
Gross area	1.33 sq. ft.
Span	2.16 ft.
Total elevator area	0.72 sq. ft.
Tailplane setting (root chord to hull datum)	2° 0'

Fin

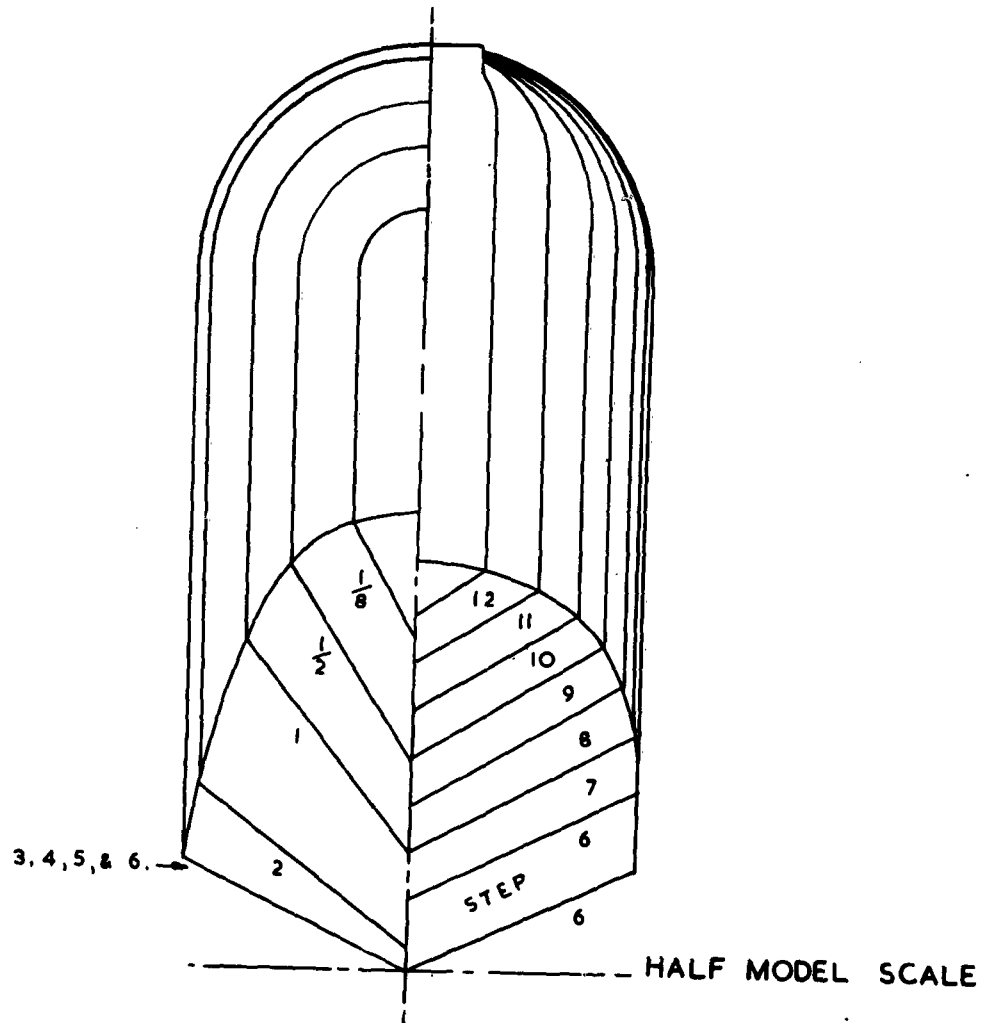
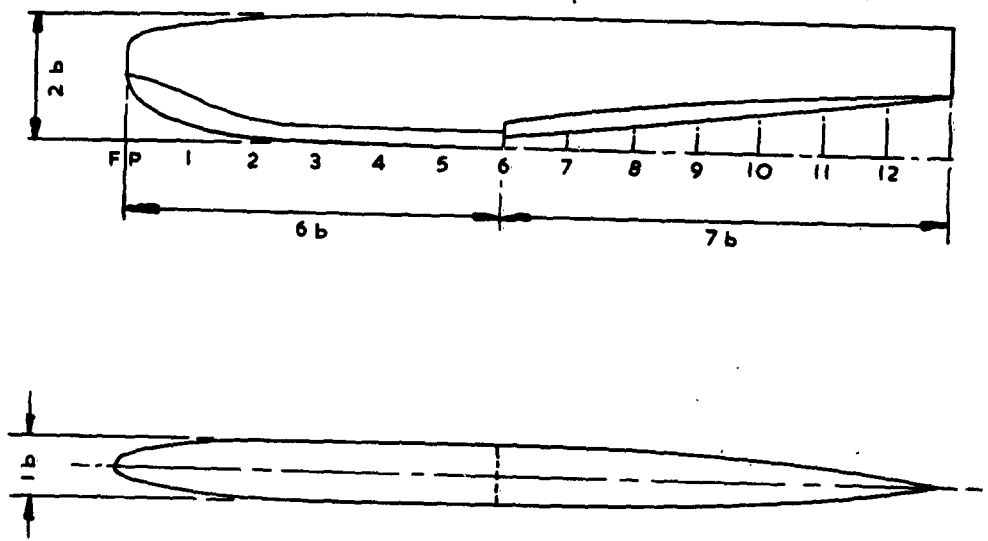
Section	R.A.F. 30
Gross area	0.80 sq. ft.
Height	1.14 ft.

General

* C.G. position	
distance forward of step point	0.237 ft.
distance above step point	0.731 ft.
* $\frac{1}{4}$ chord point S.M.C.	
distance forward of step point	0.277 ft.
distance above step point	1.015 ft.
* Tail arm (C.G. to hinge axis)	3.1 ft.
* Height of tailplane root chord L.E. above hull crown	0.72 ft.
* These distances are measured either parallel to or normal to the hull datum.	

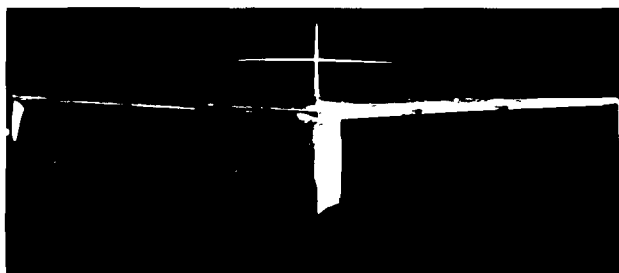
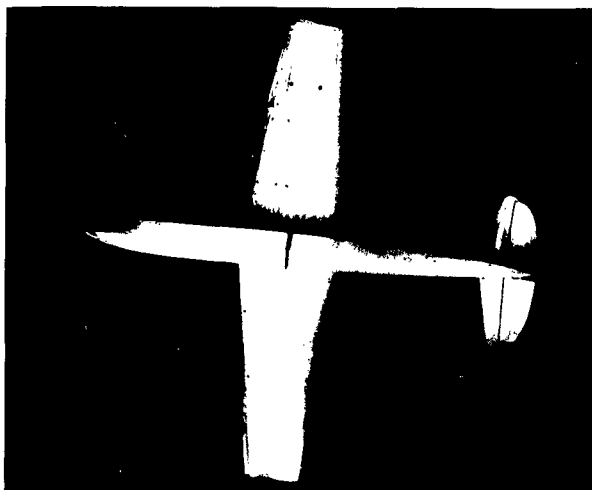
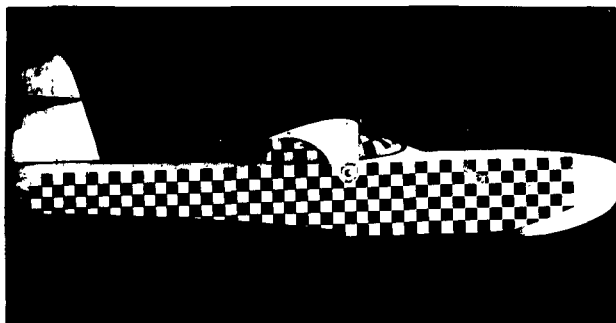
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FIG. 1.



MODEL E
HULL LINES

FIG.2



PHOTOGRAPHS OF MODEL E

FIG. 3.

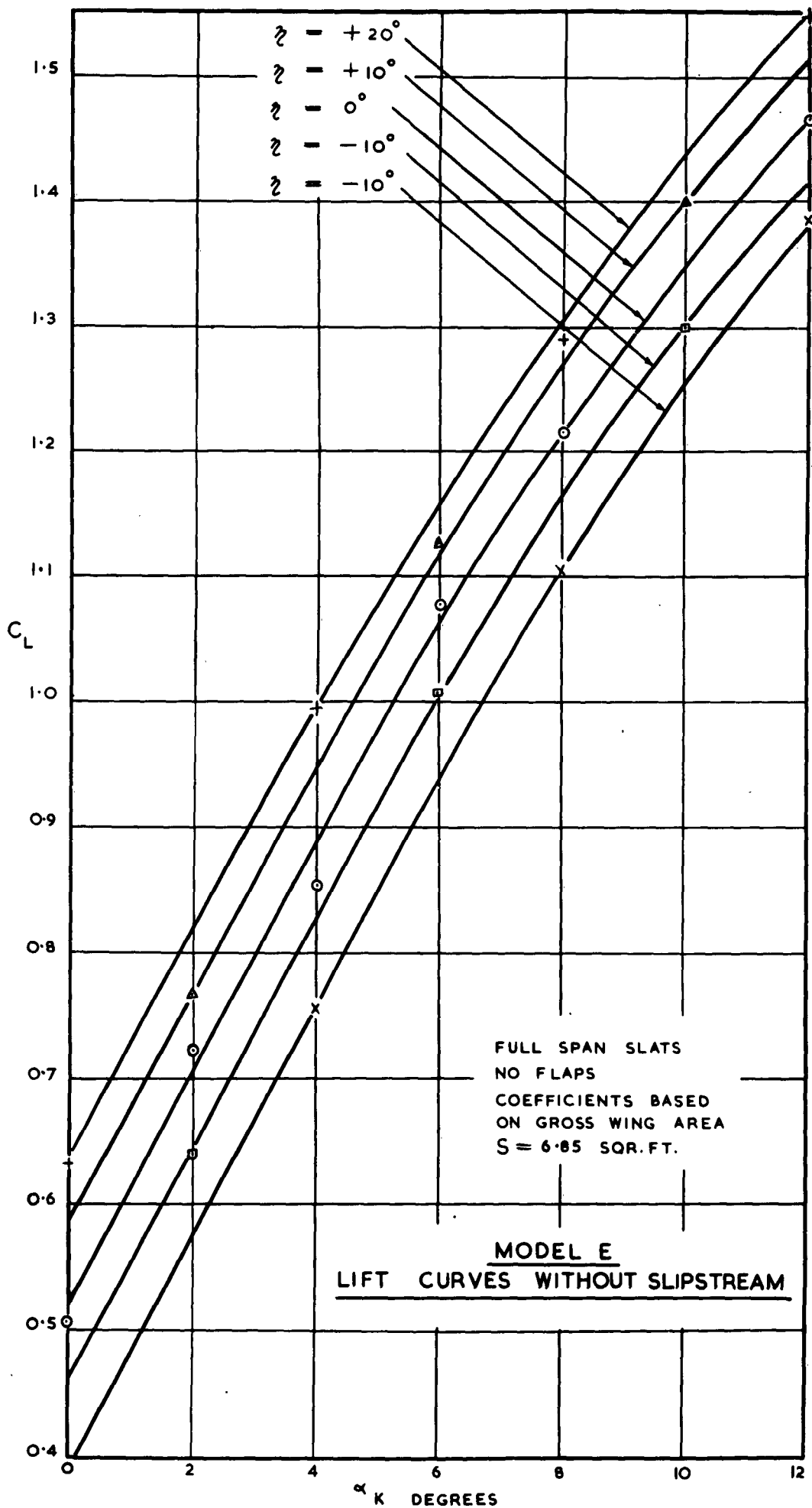
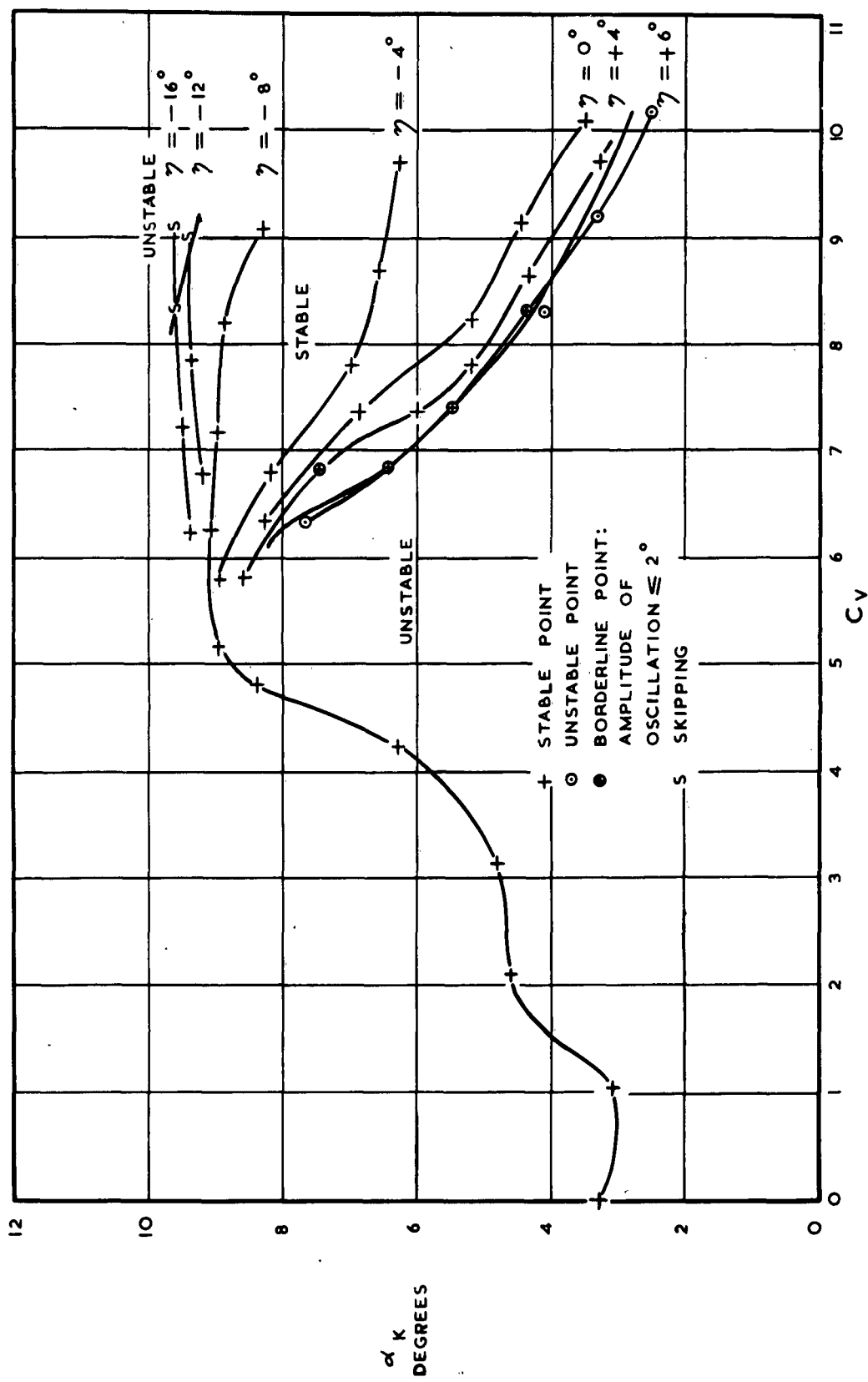
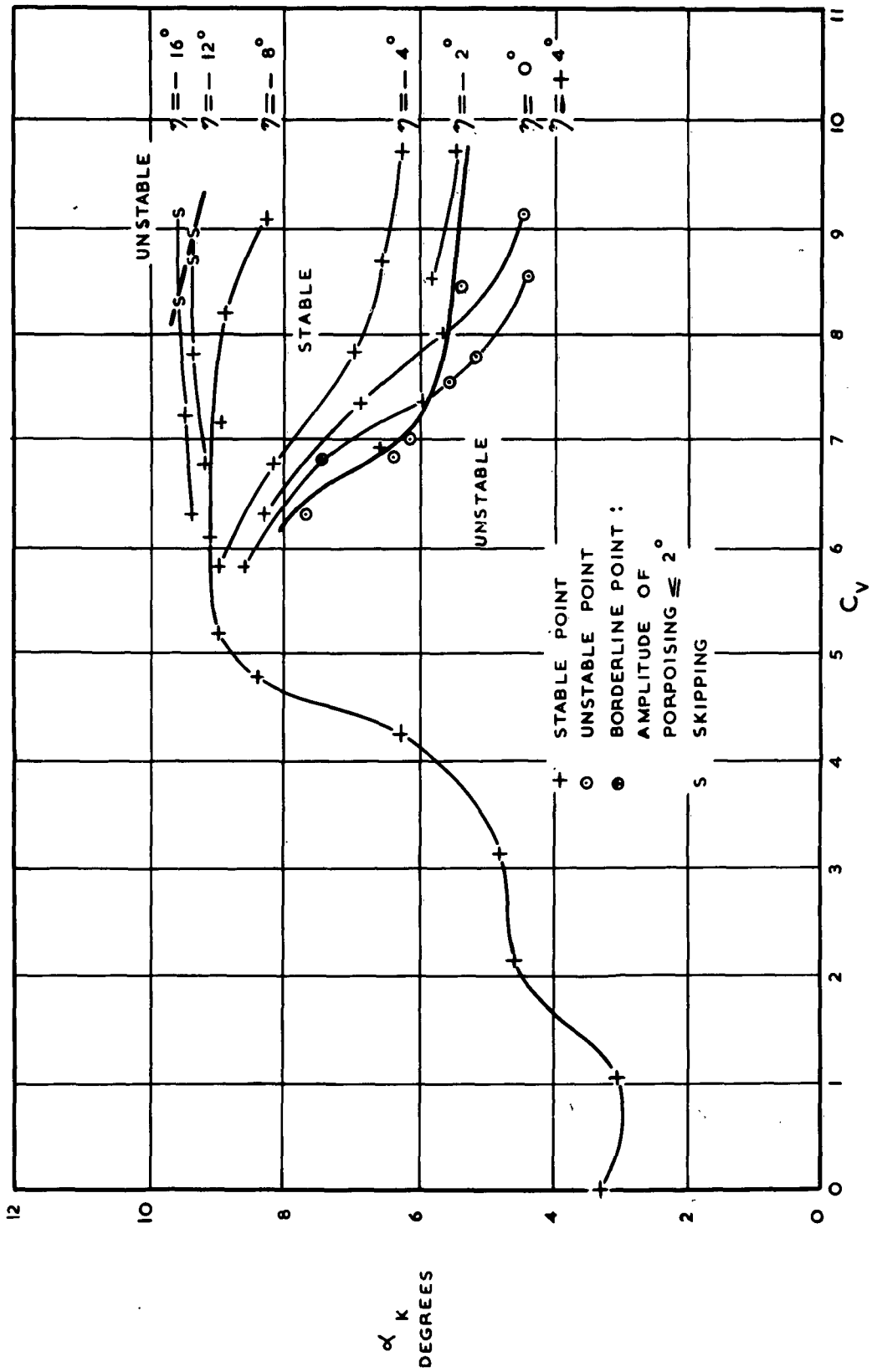


FIG. 4.



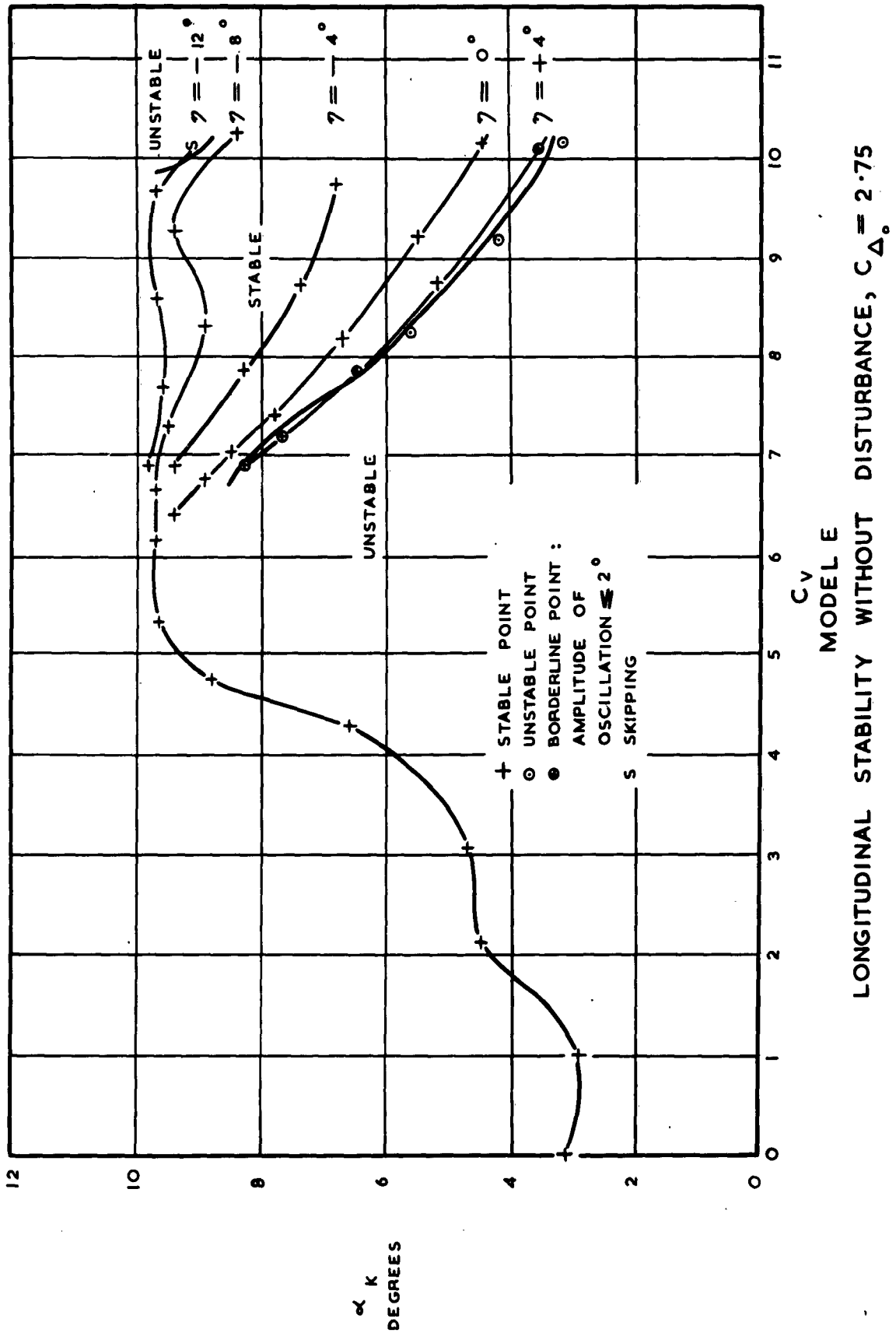
MODEL E
LONGITUDINAL STABILITY WITHOUT DISTURBANCE, $C_{\Delta_0} = 2.25$.

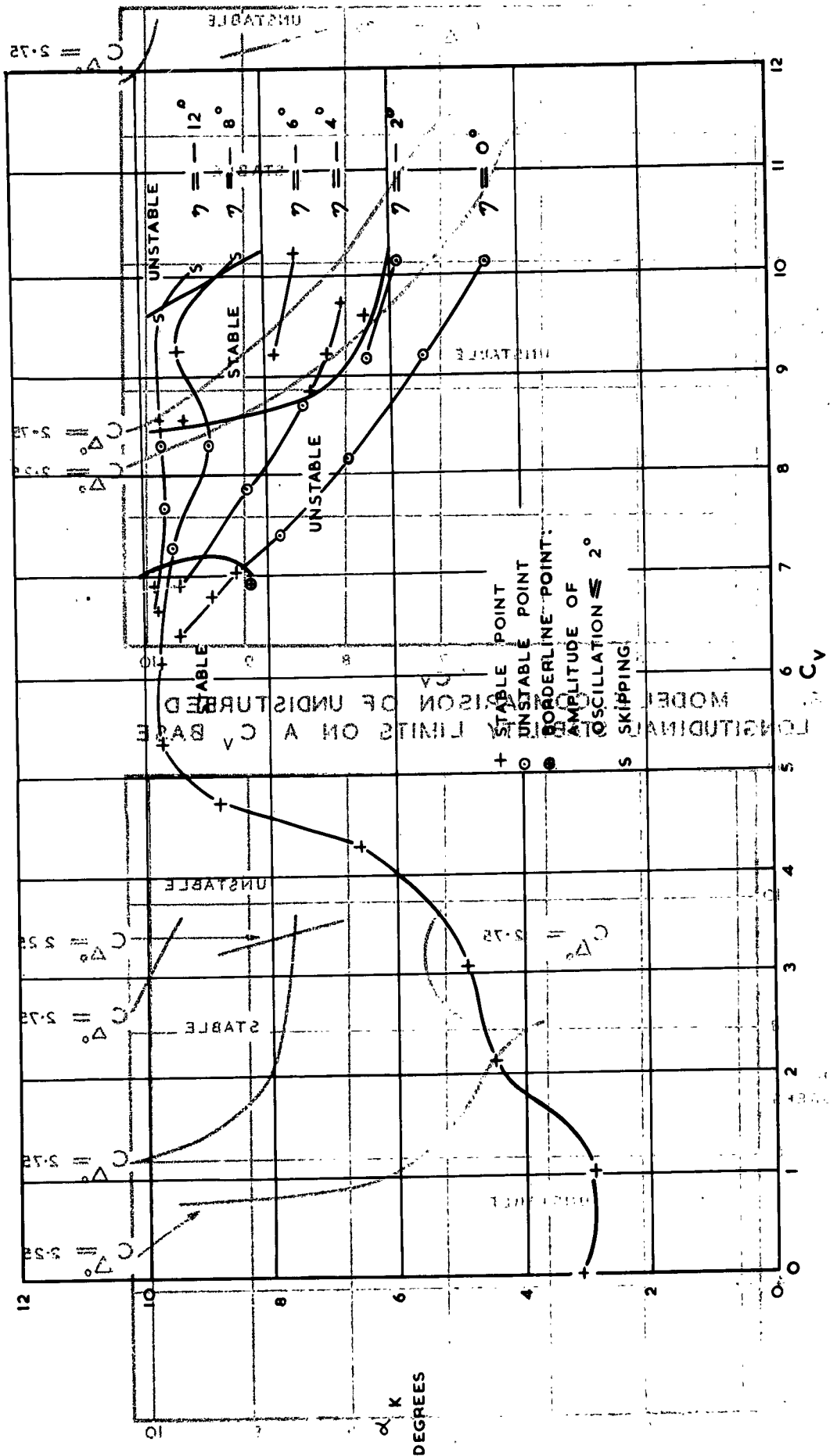
FIG. 5.



MODEL E
LONGITUDINAL STABILITY WITH DISTURBANCE, $C_{\Delta} = 2.25$

FIG. 6.





MODEL E
LONGITUDINAL STABILITY WITH DISTURBANCE, $C_{\Delta} = 2.75$

FIGS. 8 & 9.

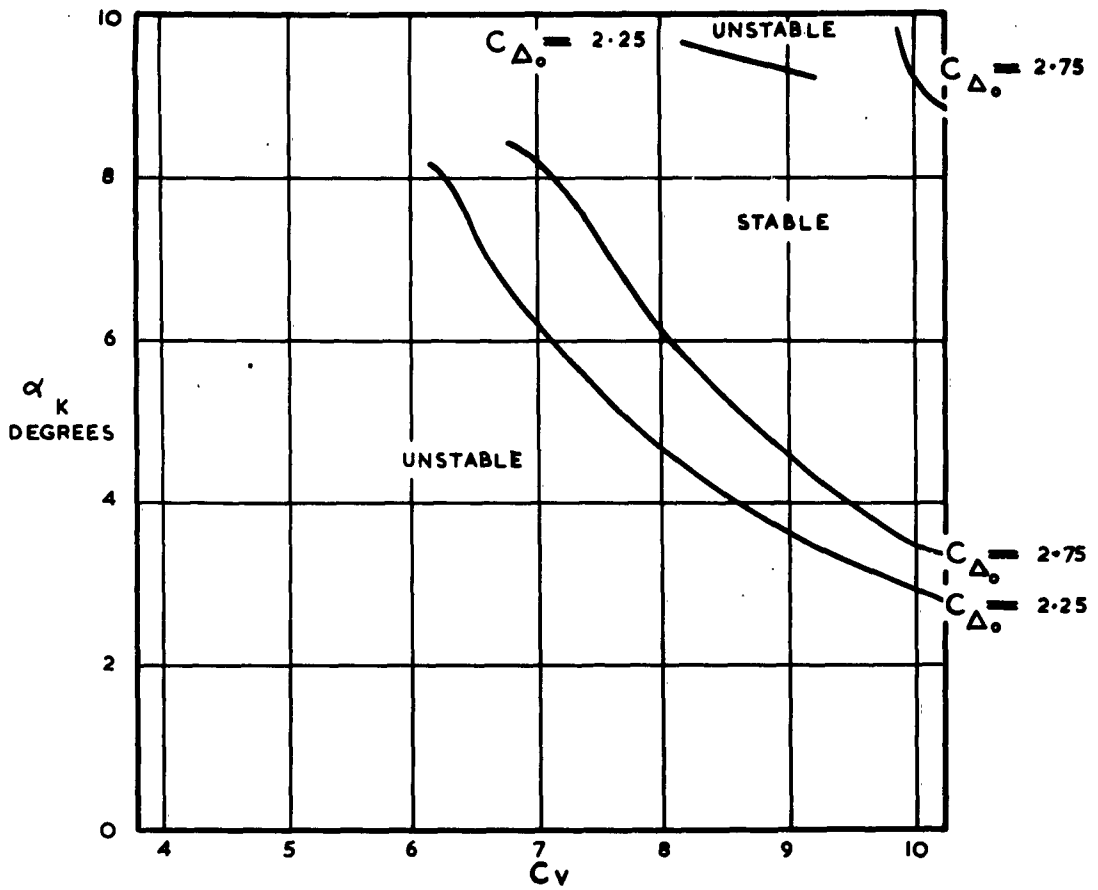


FIG. 8. MODEL E. COMPARISON OF UNDISTURBED LONGITUDINAL STABILITY LIMITS ON A C_v BASE

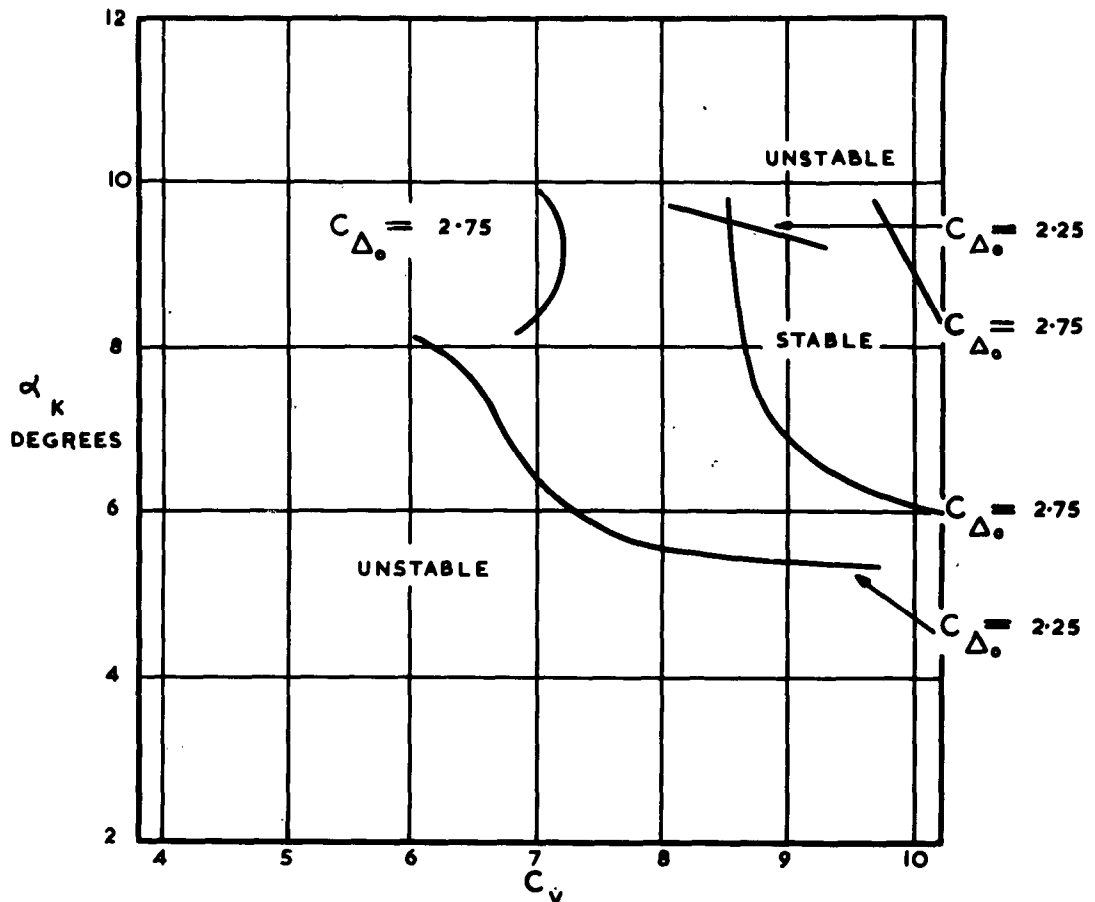
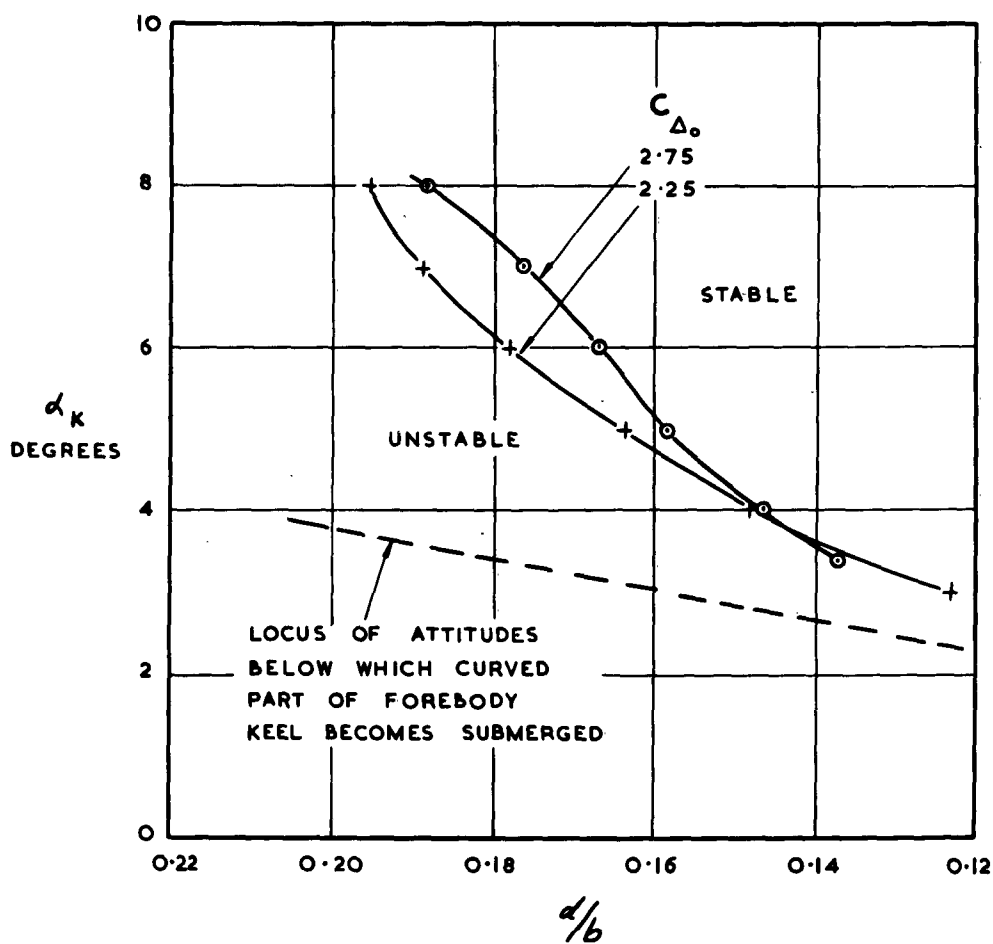


FIG. 9. MODEL E. COMPARISON OF DISTURBED LONGITUDINAL STABILITY LIMITS ON A C_v BASE

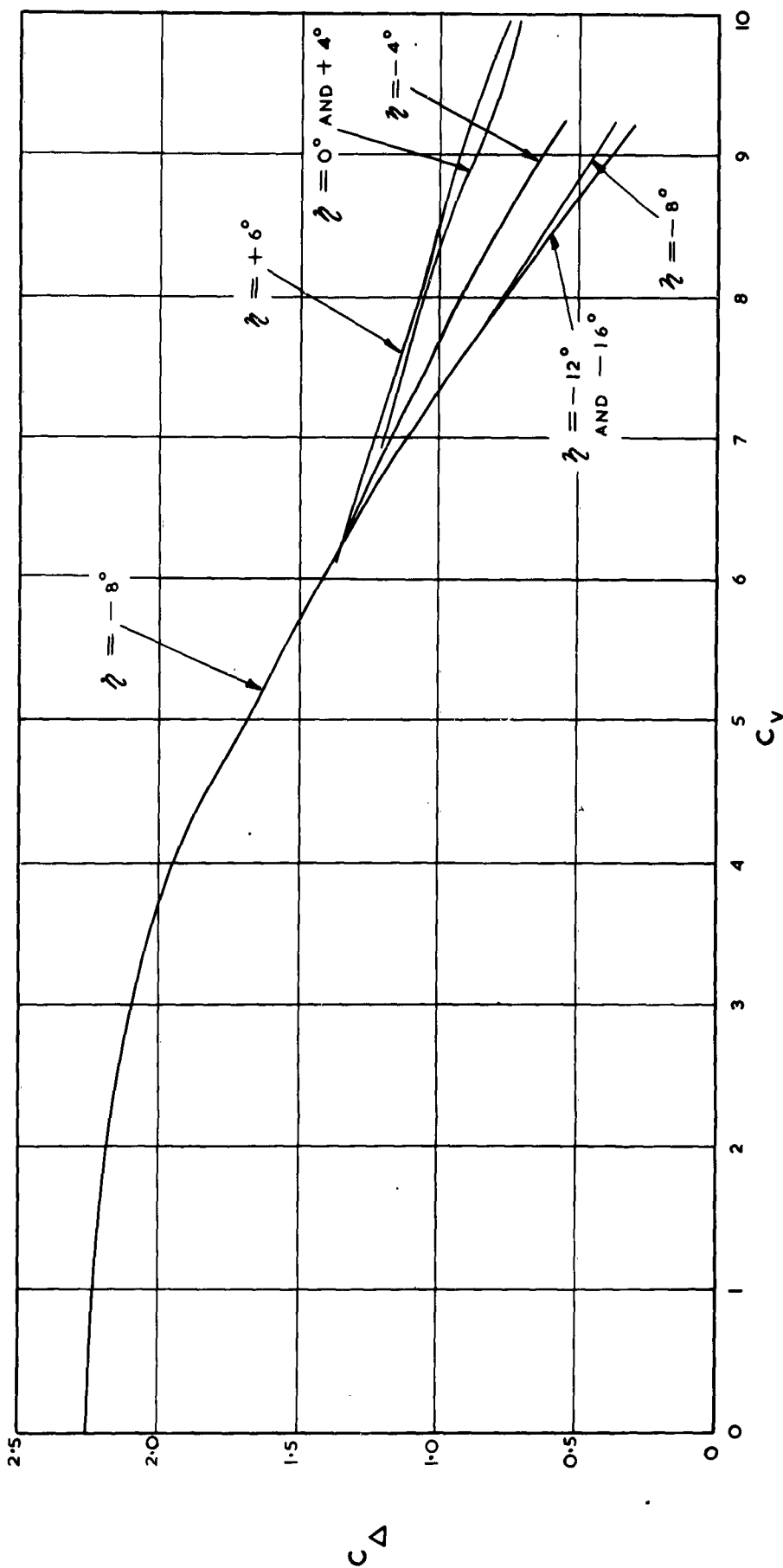
FIG. 10.



MODEL E

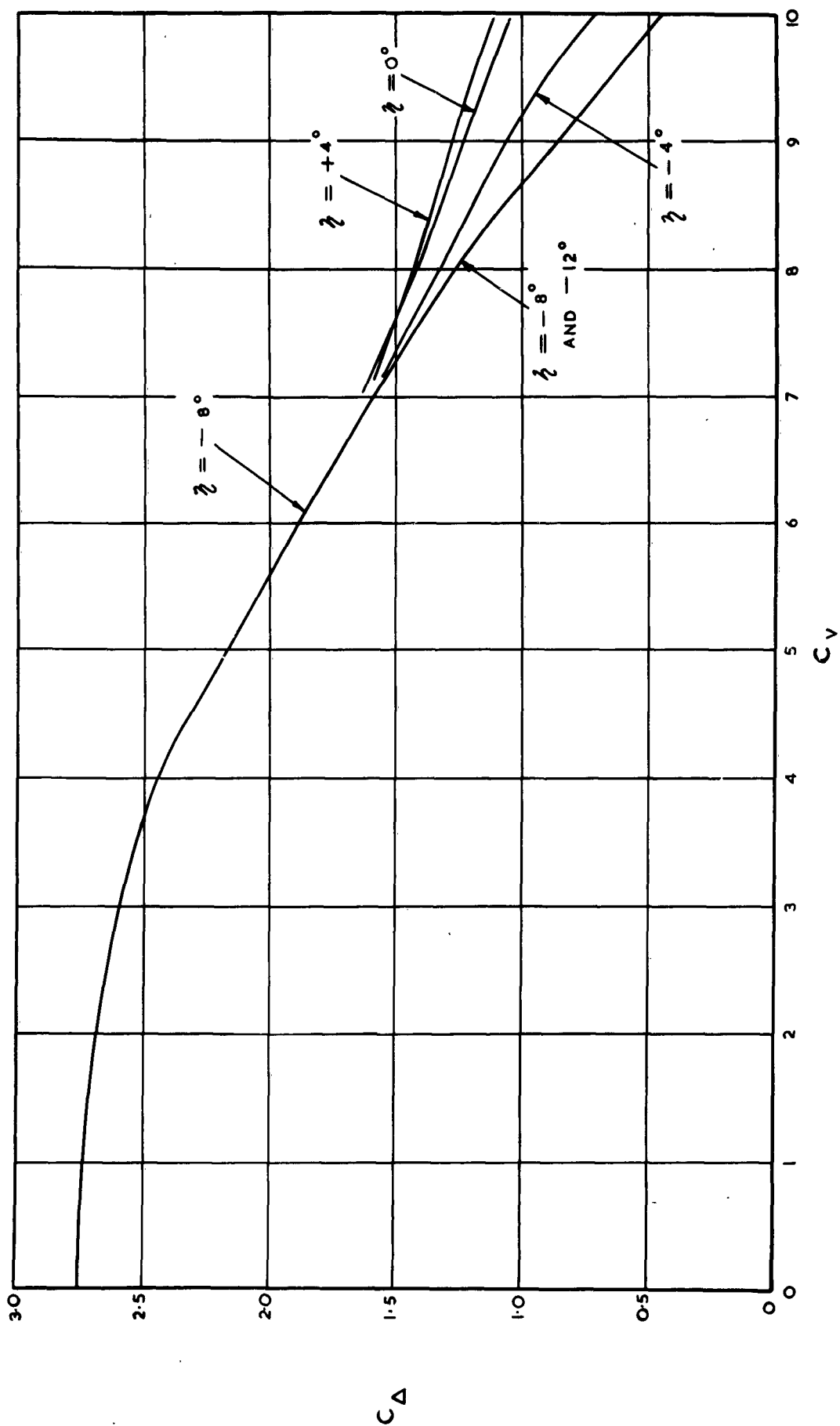
COMPARISON OF LOWER UNDISTURBED LONGITUDINAL
STABILITY LIMITS ON A DRAUGHT-BASE

FIG.II.



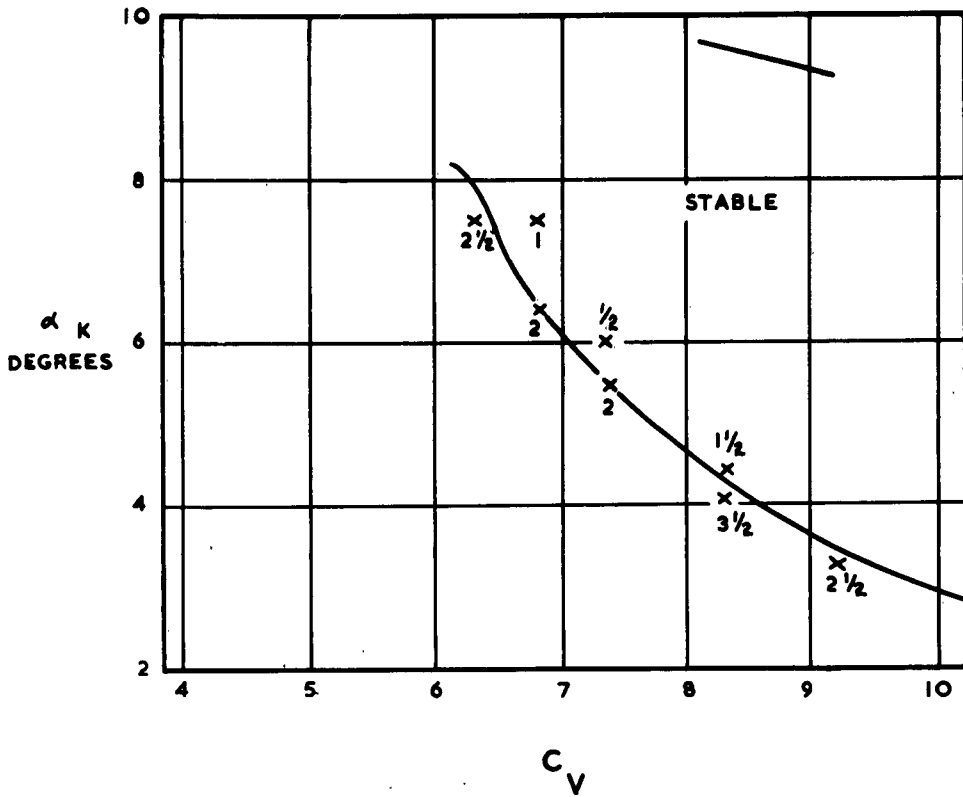
MODEL E
LOAD COEFFICIENT CURVES, $C_{\Delta_0} = 2.25$

FIG.12.



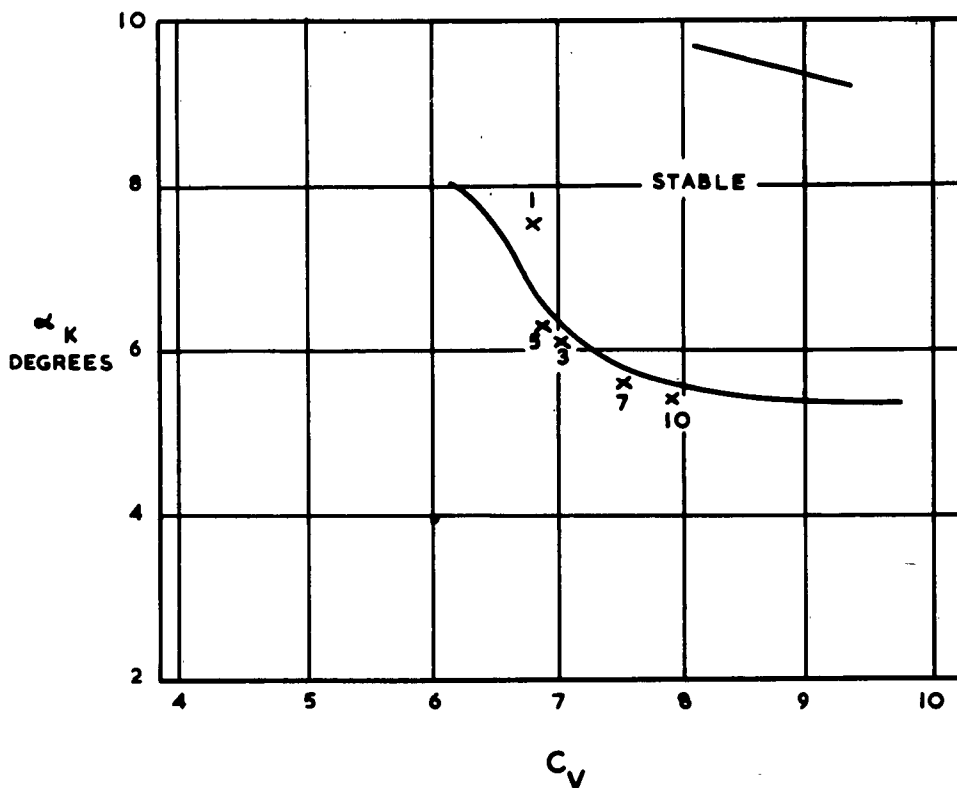
MODEL E
LOAD COEFFICIENT CURVES, $C_{\Delta_0} = 2.75$

FIG. 13.



UNDISTURBED CASE

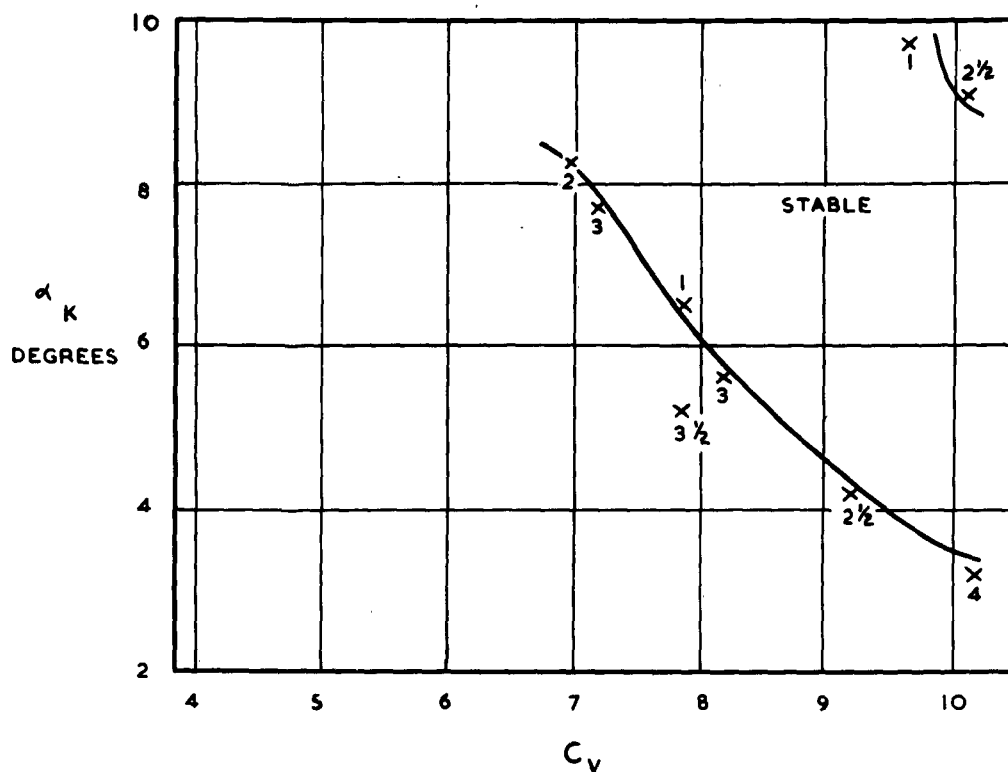
FIGURES INDICATE
AMPLITUDES OF
PORPOISING IN
DEGREES



DISTURBED CASE
MODEL E

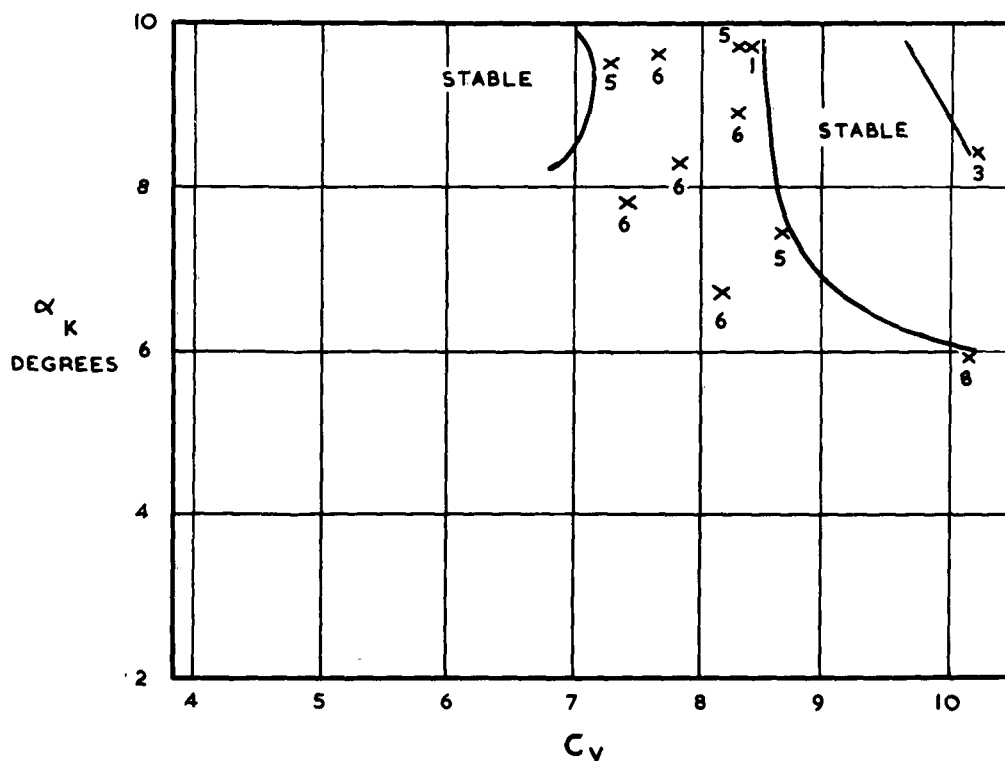
PORPOISING AMPLITUDES AND STABILITY LIMITS,
 $C_{\Delta_0} = 2.25$

FIG.14.



UNDISTURBED CASE

FIGURES INDICATE
AMPLITUDES OF
PORPOISING IN
DEGREES



DISTURBED CASE

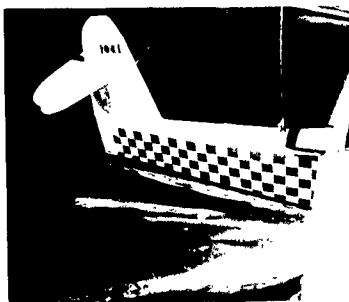
MODEL E

PORPOISING AMPLITUDES AND STABILITY LIMITS,
 $C_{\Delta_0} = 2.75$

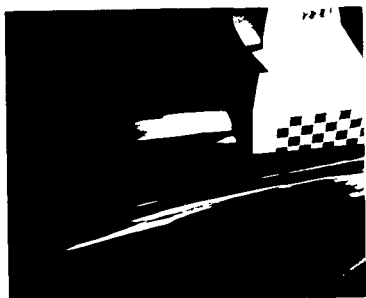
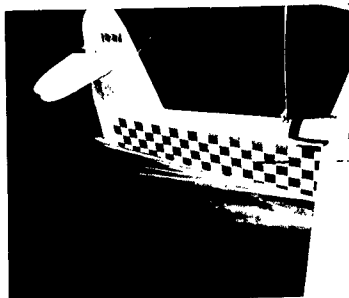
FIG. 15



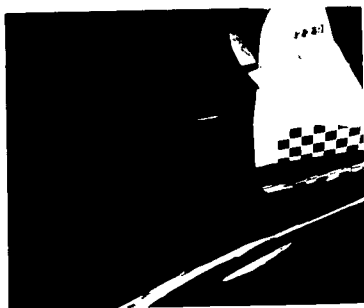
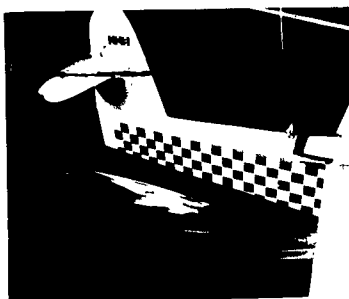
(a)
 $\gamma = -16^\circ$
 $C_v = 6.04$
 $\alpha_k = 9.3^\circ$



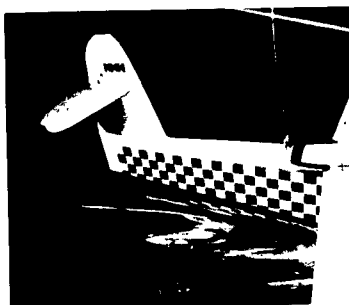
(b)
 $\gamma = -8^\circ$
 $C_v = 8.45$
 $\alpha_k = 8.8^\circ$



(c)
 $\gamma = 0^\circ$
 $C_v = 8.45$
 $\alpha_k = 5.0^\circ$



(d)
 $\gamma = 0^\circ$
 $C_v = 6.06$
 $\alpha_k = 8.6^\circ$



(e)
 $\gamma = -4^\circ$
 $C_v = 7.35$
 $\alpha_k = 7.4^\circ$

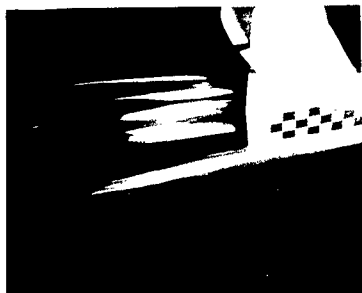
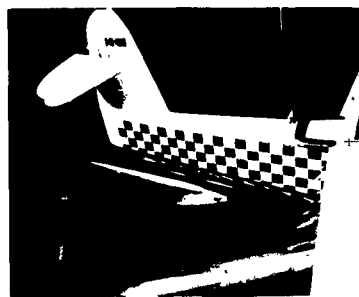


MODEL E
 WAKE PHOTOGRAPHS
 $C_{\Delta_0} = 2.25$

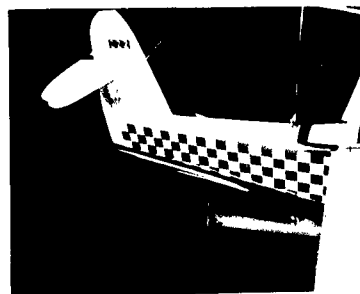
FIG. 16



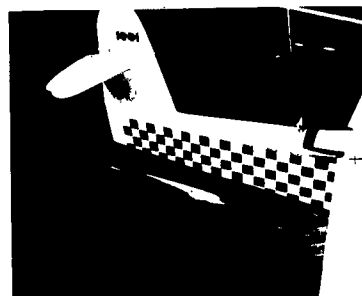
(a)
 $\gamma = -16^\circ$
 $C_v = 7.02$
 $\alpha_k = 9.9^\circ$



(b)
 $\gamma = -8^\circ$
 $C_v = 8.95$
 $\alpha_k = 9.3^\circ$



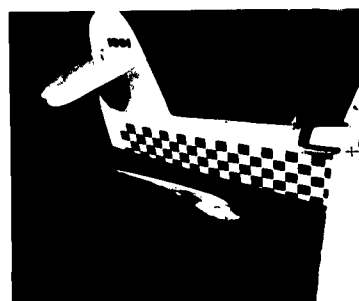
(c)
 $\gamma = 0^\circ$
 $C_v = 9.16$
 $\alpha_k = 5.4^\circ$



(d)
 $\gamma = 0^\circ$
 $C_v = 6.98$
 $\alpha_k = 8.6^\circ$



(e)
 $\gamma = -4^\circ$
 $C_v = 7.93$
 $\alpha_k = 8.2^\circ$

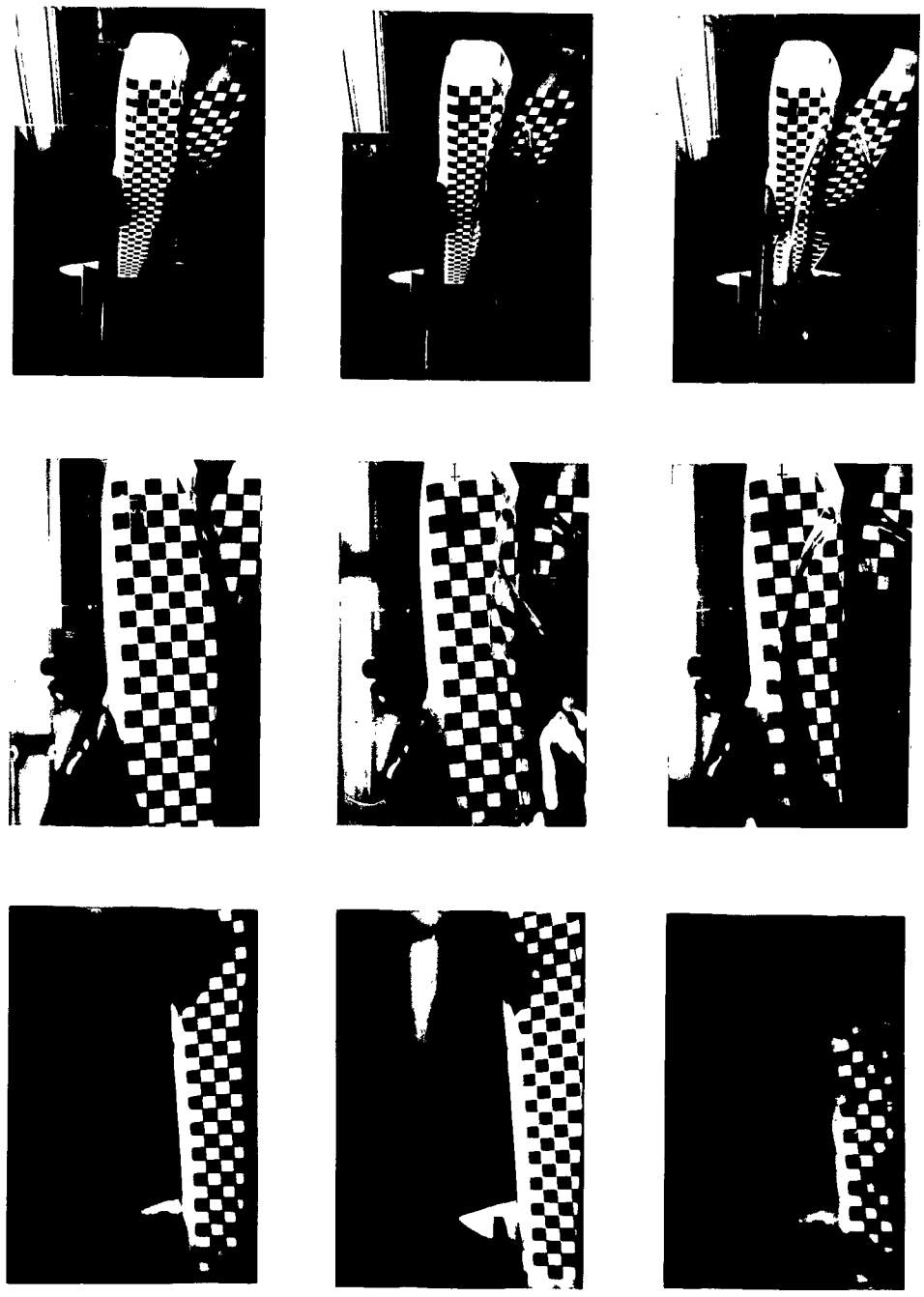


MODEL E

WAKE PHOTOGRAPHS

$C_{\Delta_0} = 2.75$

FIG. 17



(a)
 $\gamma = -8^\circ$
 $C_v = 1.07$
 $\alpha_k = 3.1^\circ$

(v)
 $\gamma = -8^\circ$
 $C_v = 2.17$
 $\alpha_k = 4.6^\circ$

(c)
 $\gamma = -8^\circ$
 $C_v = 3.18$
 $\alpha_k = 4.8^\circ$

MODEL E
SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2.25, (1)$

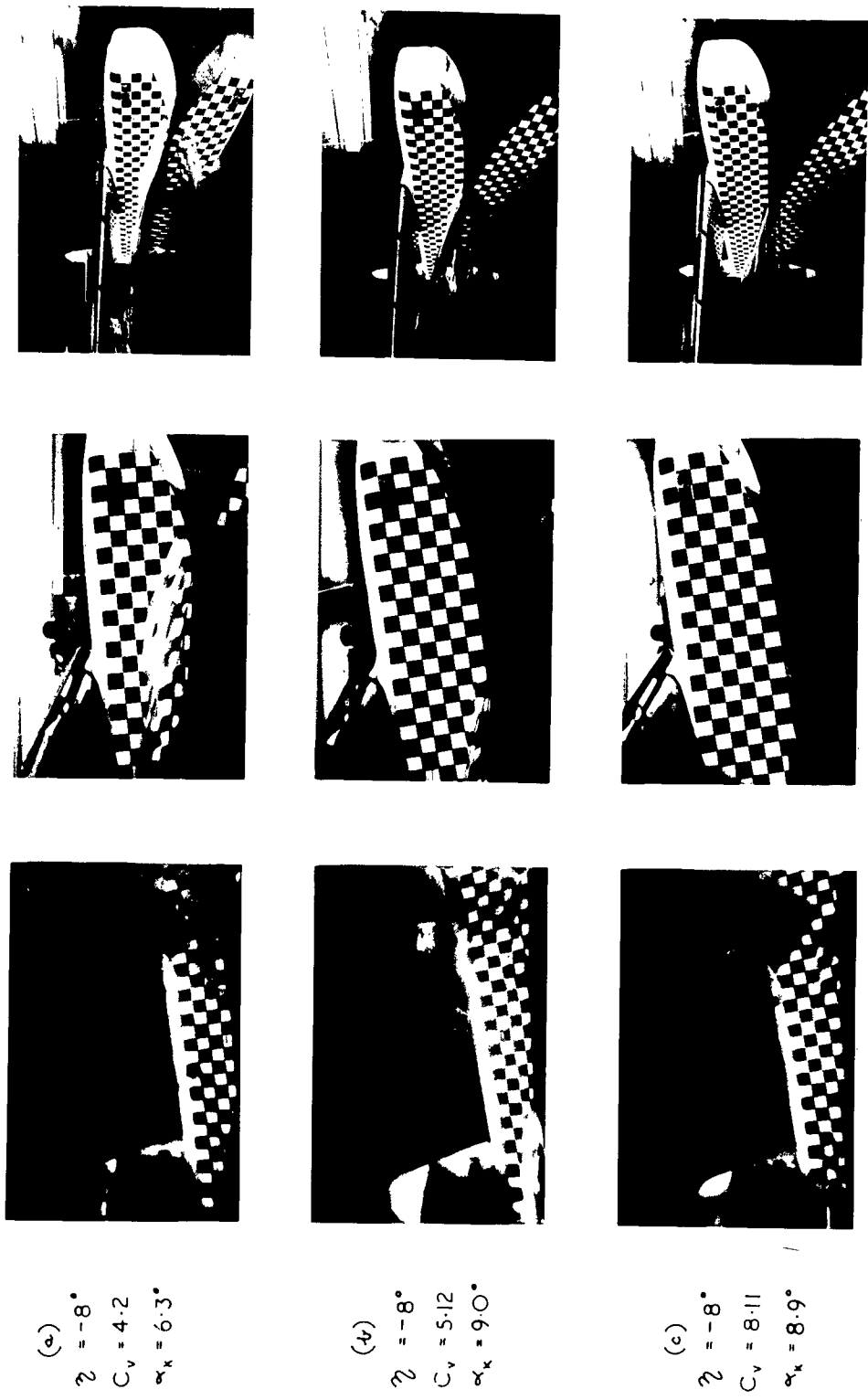
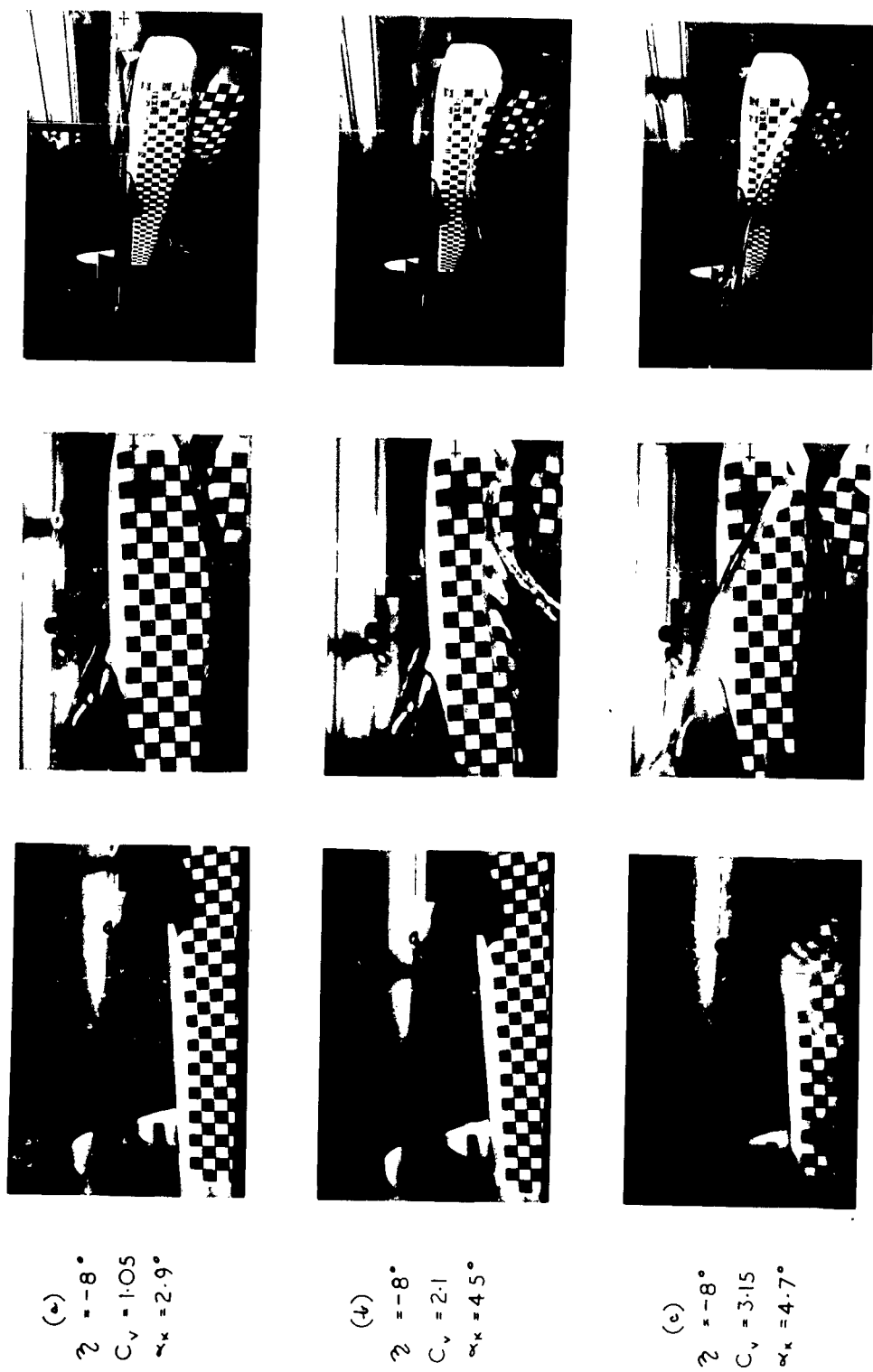


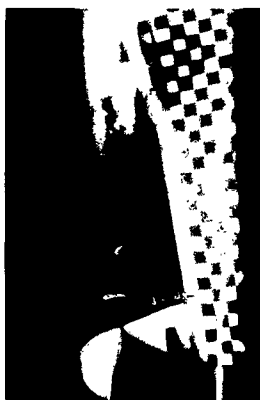
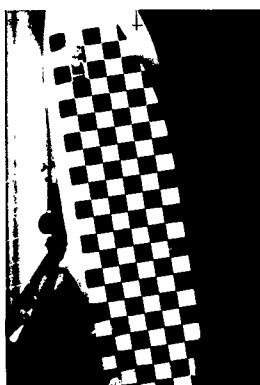
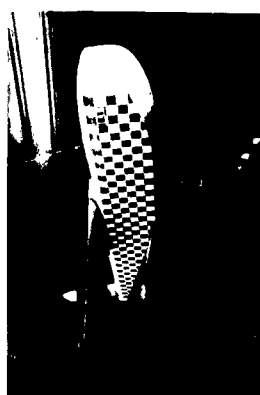
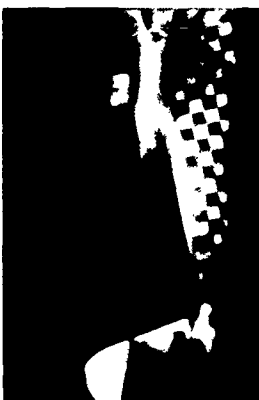
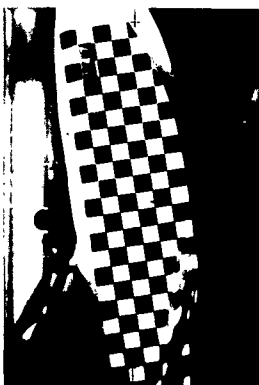
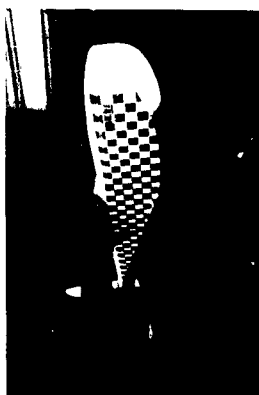
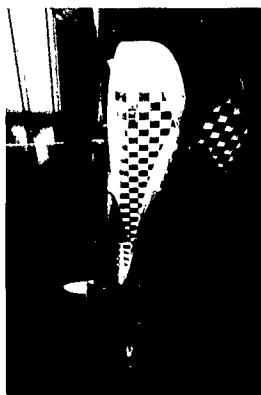
FIG.18

MODEL E
 SPRAY PHOTOGRAPHS, $C_{D_0} = 2.25, (2)$

FIG. 19



MODEL E
 SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2.75, (1)$



(a)
 $\gamma = -8^\circ$
 $C_v = 4.17$
 $\alpha_x = 62^\circ$

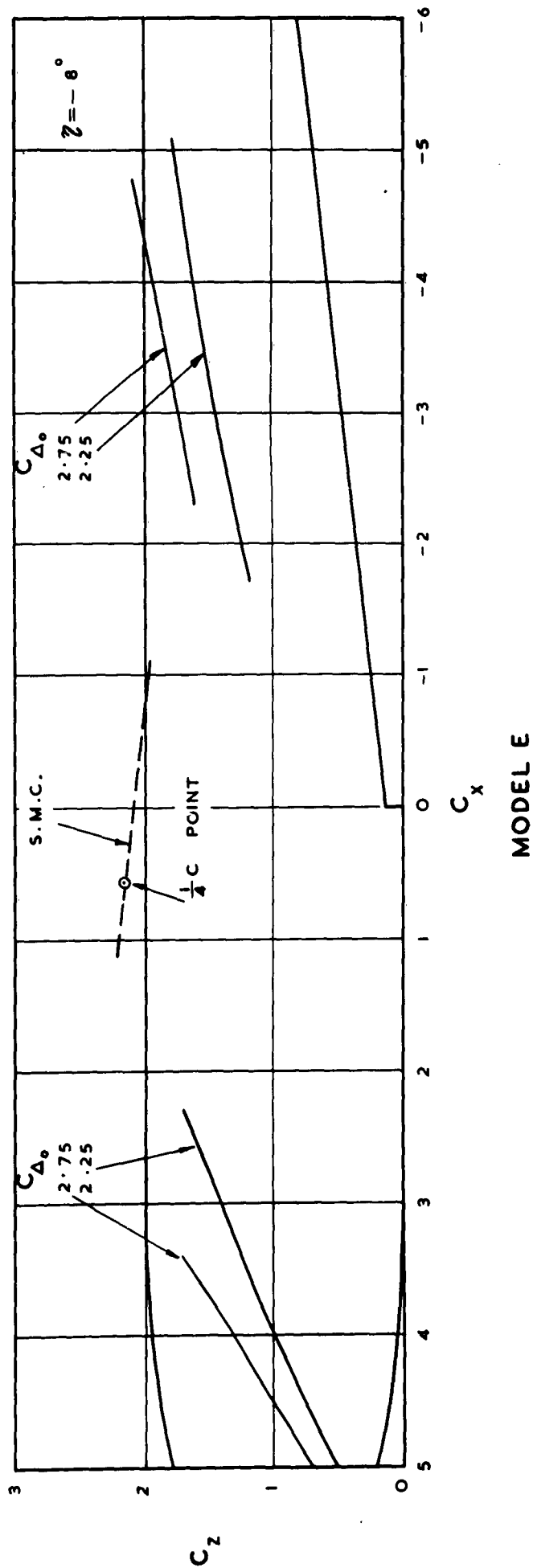
(b)
 $\gamma = -8^\circ$
 $C_v = 5.2$
 $\alpha_x = 9.7^\circ$

(c)
 $\gamma = -8^\circ$
 $C_v = 8.23$
 $\alpha_x = 8.9^\circ$

FIG.20

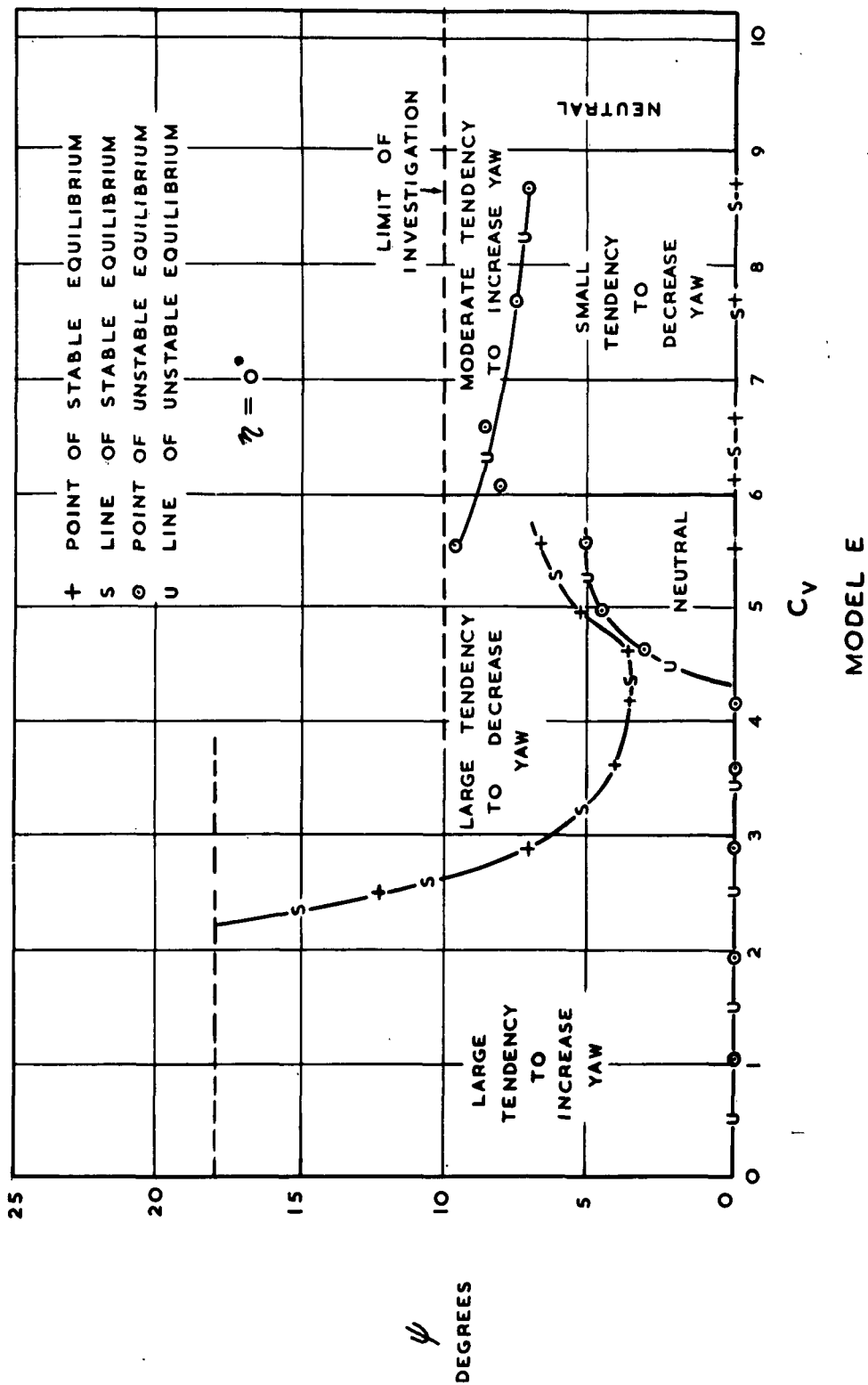
MODEL E
 SPRAY PHOTOGRAPHS, $C_{D_0} = 2.75(2)$

FIG. 21.



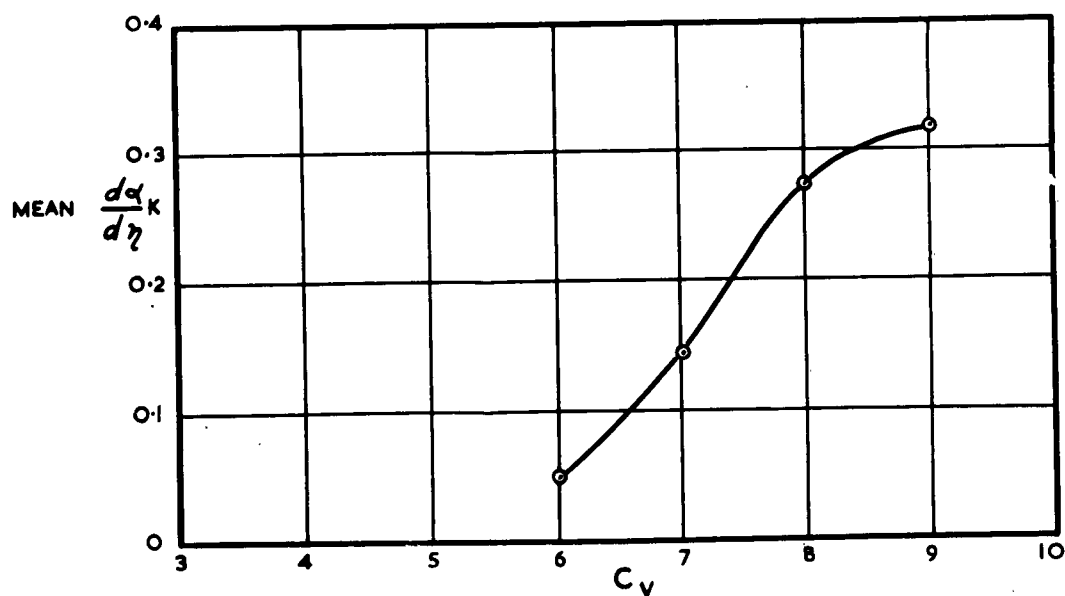
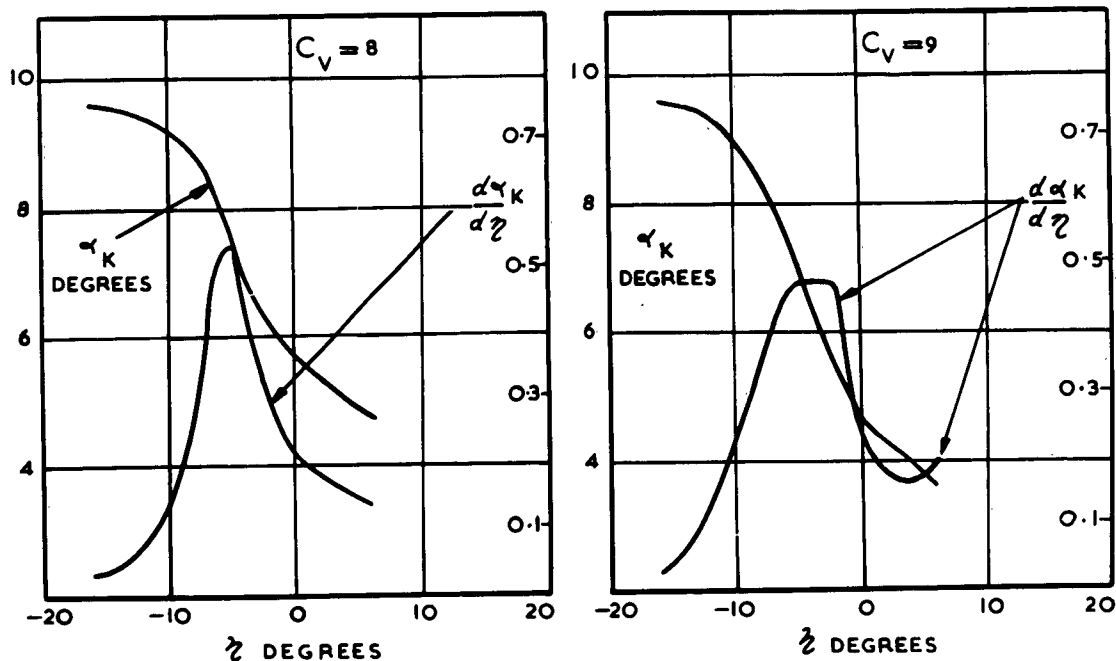
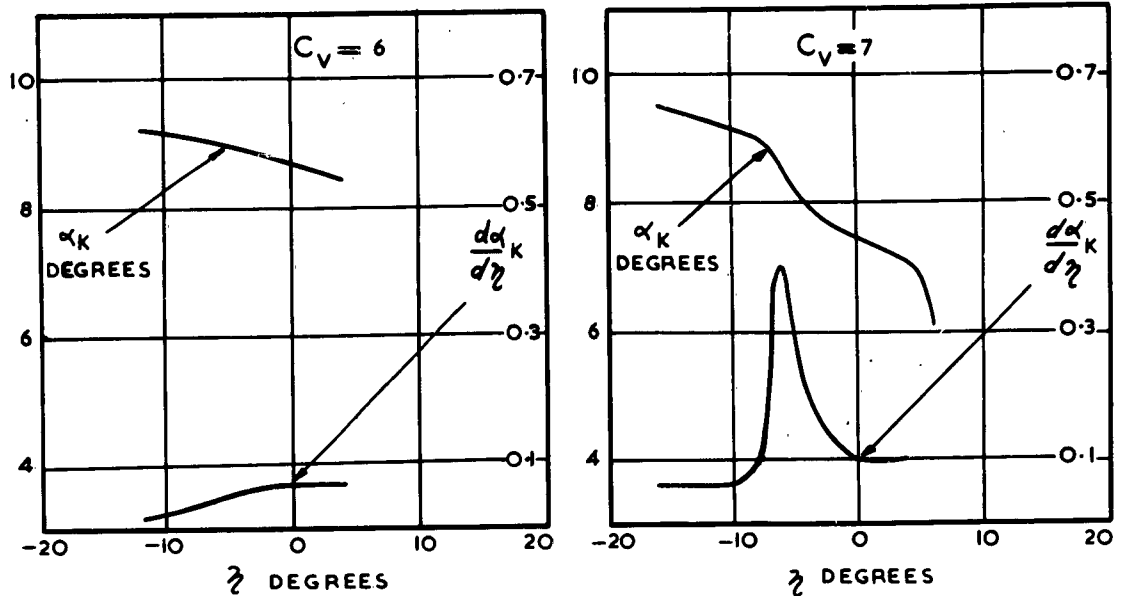
PROJECTIONS OF SPRAY ENVELOPES ON PLANE OF SYMMETRY OF MODEL E

FIG. 22.



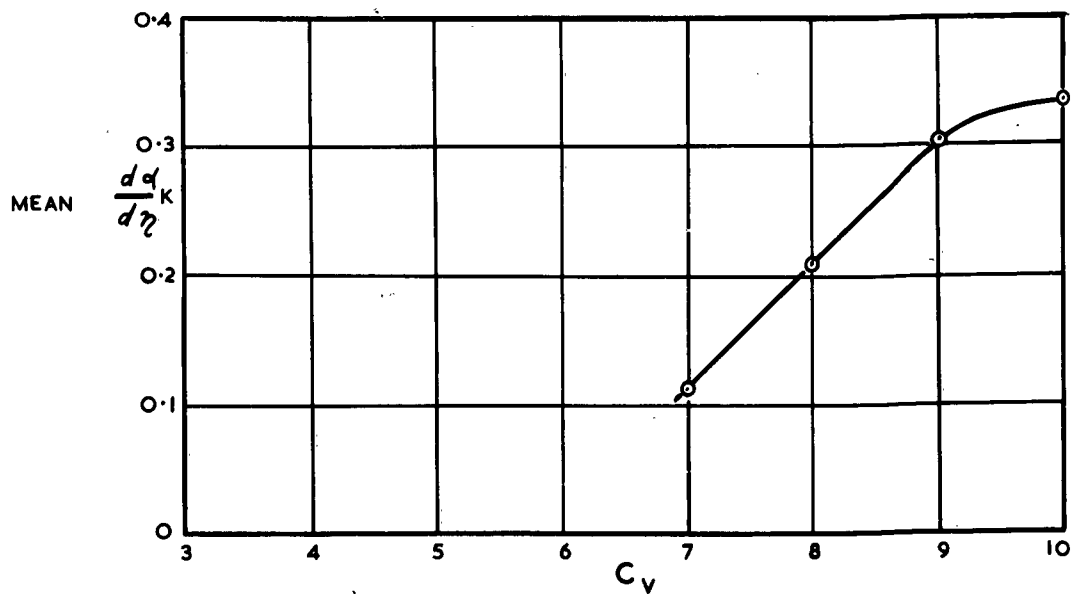
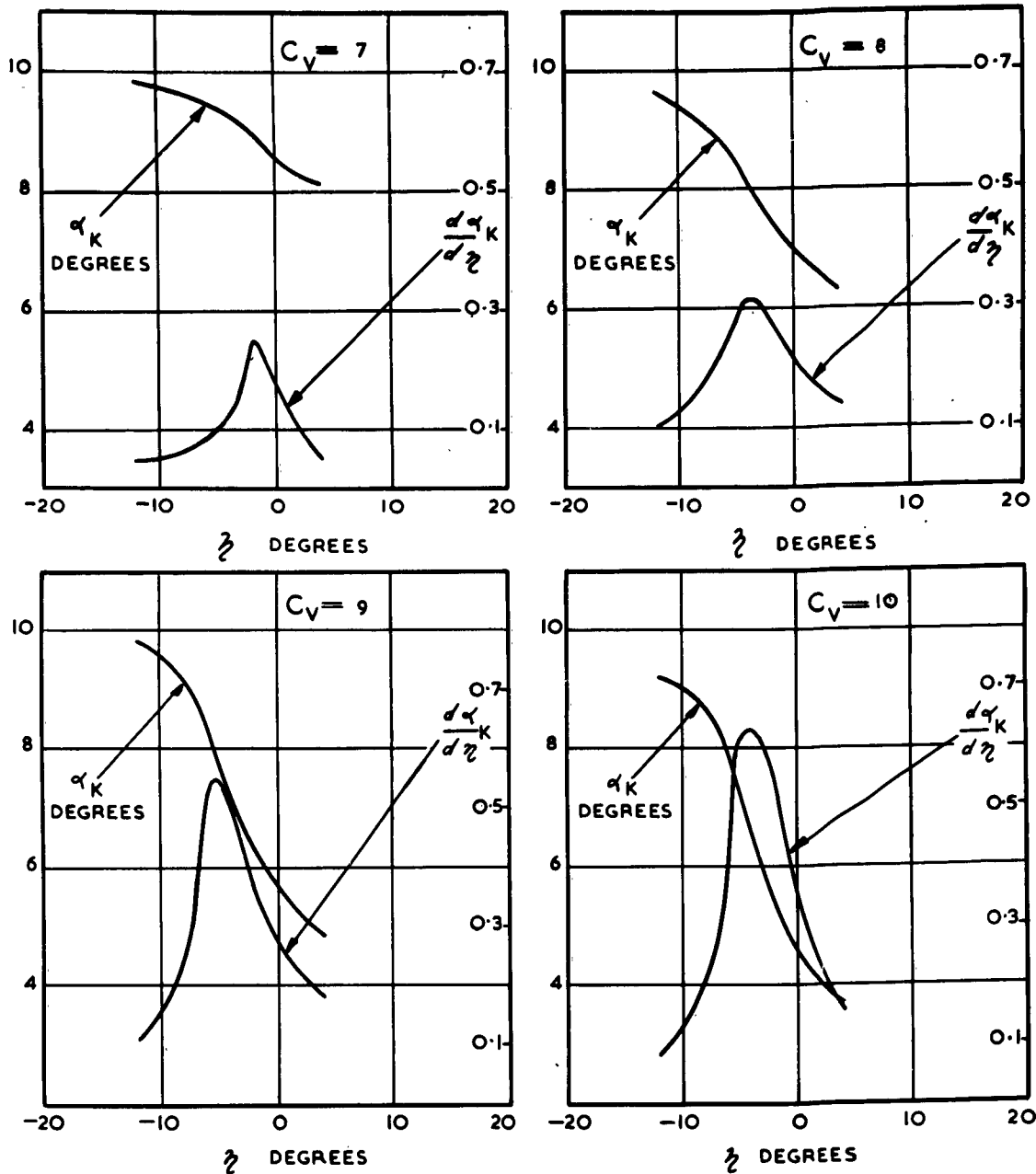
DIRECTIONAL STABILITY, $C_{\Delta} = 2.75$

FIG.23.



MODEL E ELEVATOR EFFECTIVENESS, $C_{\Delta_0} = 2.25$

FIG. 24.



MODEL E ELEVATOR EFFECTIVENESS, $C_{\Delta_0} = 2.75$



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